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The Incidence of Larvae of *Porrocaecum decipiens* in the Flesh of Cod

by BENNET B. RAE, M.A., B.Sc., Ph.D., F.R.S.E.

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Marine Laboratory, Aberdeen

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The Incidence of Larvae of *Porrocaecum decipiens* in the Flesh of Cod

INTRODUCTION

Most, if indeed not all, fish are infested by one or more species of the various groups of parasitic worms. In general, the occurrence of these worms presents no difficulty to fish merchants, since, normally, they are discarded during the gutting and washing of the fish. Young stages of certain worm parasites, however, not infrequently penetrate the muscular tissues of fish where they may remain undetected until the fish is cut up prior to retail sale or even to cooking by the housewife. This creates a problem which varies in magnitude according to the species of fish involved, to the frequency and degree of the infestation and to the extent of the affected grounds.

Worm infestation of fish in the past has caused losses to fishermen and to fish merchants alike and, consequence, has necessitated special precautions in regard to certain species, which may add considerably to the production or processing costs. The problem is still further aggravated by the fact that the presence of parasitic worms is often unavoidably overlooked until the fish reaches the consumer. Consequently, some health authorities have been obliged to adopt certain measures with the object of insuring the freedom from parasites of fish sold for human consumption. These measures vary from country to country—some being on a national basis, while others, as in the United Kingdom, remain chiefly the responsibility of local authorities. In view of the slowly awakening interest of the general public in the cleanliness and purity of food it seems probable that regulations applicable to fish will become more stringent in the course of time.

One of the most troublesome parasites in this connection is the larval stage of an ascarid nematode, *Porrocaecum* (=*Terranova*=*Phocanema*) *decipiens* (Krabbe) which occurs in the muscles and other tissues of many species of fish in both the northern and southern hemispheres. The adult stage of this worm has long been known to be present in the alimentary canal of seals. Baylis (1916) expressed the view that fish became infested by ingesting the eggs of the parasite previously extruded with seal faeces and that seals derived the worms by eating infested fish. As the possibility of the infestation of large fish such as cod by direct ingestion of the eggs appears rather remote it seems likely that some other animal, possibly an invertebrate, serves either as a first intermediate host in the life cycle of the worm or as a "transporter" or passive host between the seal and the fish. If this unknown animal should act as a true host to the parasite the fish would then represent a second intermediate host.

Although, in the North Atlantic, various economically important fish, including salmon, are parasitised by this worm, the most serious infestation known so far occurs in the muscle tissues of cod, *Gadus morhua* L. (*G. callarias*). In some coastal regions of eastern Canada this infestation presents a major problem to the fish trade with the result that a considerable amount of research has been devoted in recent years to its investigation in an effort to reduce its incidence (Scott, 1953, 1954, 1955; Scott and Fisher, 1958; Scott and Martin, 1957, 1959; Scott and Black, 1960; Templeman *et al*, 1957; Myers, 1959, 1960; Crampton *et al*, 1960). Infestation of cod by the same worm has also been recorded from Iceland and from other northern seas (Kahl, 1939).

In recent years some anxiety has also been caused by the apparent increase in the numbers of infested cod round the Scottish coast. During the summer of 1958 reports were received from fish merchants of the occurrence of nematode worms in the flesh of codling from the Firth of Forth and from the Moray Firth. As these reports, which were accompanied by specimens of wormy codling, indicated a higher degree of infestation than any hitherto experienced in normal filleting operations from these grounds, steps were taken immediately to study the problem on Scottish research vessels. At the same

time further requests for information on the subject were addressed through Fishery Officers to fishermen and to fish merchants. This latter approach encountered difficulties. In the first place the bulk of the fish caught on Scottish coastal grounds is despatched to inland markets as it comes off the fishing vessels, i.e., not filleted. Many fishermen and merchants, therefore, have little opportunity of knowing whether these fish are worm-infested or not, until and unless they are informed by consignees. Secondly, merchants are mainly concerned with the appearance and quality of the fish they buy and are not always interested in where it is caught.

In spite of these difficulties, enquiries succeeded in showing that those Scottish fish merchants who habitually fillet fish, whether for local or for other markets, had observed an appreciable increase in the worm infestation of cod from certain coastal fishing grounds since the end of the Second Great War. One firm estimated that 3% of codling from the Firth of Forth were worm infested; another stated that 5% of Moray Firth cod were similarly affected. These figures were more than confirmed by the first research observations in these localities. It was also ascertained that the estimated infestation of cod in the Moray Firth tended to increase as one proceeded westwards into the Firth.

COLLECTION AND TREATMENT OF MATERIAL

From July 1958 onwards cod of all sizes caught by the Scottish research vessels were examined for the presence of nematodes in the flesh of the fish. In view of the commercial implications of the problem and the need for a rapid survey of the situation, it was decided to employ a routine previously used with success in another case of worm infestation of fish (Rae, 1958). This consisted of the measurement of the fish, the noting of their sex and maturity, the filleting and the examination of the exposed flesh for worms, which were counted. Each fillet was then cross-sectioned at intervals of from one to two inches, or, if thin enough, candled, and any additional worms thus discovered were added to the total. The location of the worms in the flesh was also recorded, for example, whether in the right side or in the left, whether dorsally or ventrally and if the latter whether in the "flaps" or "lugs" or in the more desirable parts of the fillet. These methods were found to be particularly suitable for application at sea on normal research cruises. During the examination of the cod, which throughout was macroscopic in character, care was taken to employ as constant a technique as possible, in order to ensure comparable results. Additional notes were also made on the stomach contents of the fish and of the incidence of encysted nematodes on the organs and tissues of the body cavity, although of course these were not included in the flesh counts. In this report, therefore, the term infestation refers to infestation of the flesh.

Latterly, samples of cod have been purchased from commercial sources and examined at the Marine Laboratory. These have been obtained from localities in which it has been impracticable for a research vessel to operate or for the purpose of augmenting research records.

The numbers of cod examined from all sources since July 1958 and the numbers in each statistical rectangle of the North Sea and western grounds found to have worms in their flesh are given in four size-groups in Figure 1. The range and composition of the four groups are as follows:—

(1) 11-30 cm, comprising immature codling up to about 3 years of age;

(2) 31-50 cm, mainly immature and adolescent codling 3 and 4 years of age, but including also a small number of fish about to spawn for the first time;

(3) 51-70 cm fish preparing to spawn for the first time and the smaller adult fish, mainly 5 and 6 years old;

(4) 71-115 cm, adult cod 6 years of age and over.

During the investigations, samples of nematodes from the cod were preserved for identification of the species. Latterly several hundred worms were measured for comparison with records from other sources.

In most of the research vessel catches all the cod were examined but, where lack of time or large numbers of fish prevented this from being done, samples were selected to cover proportionally the entire

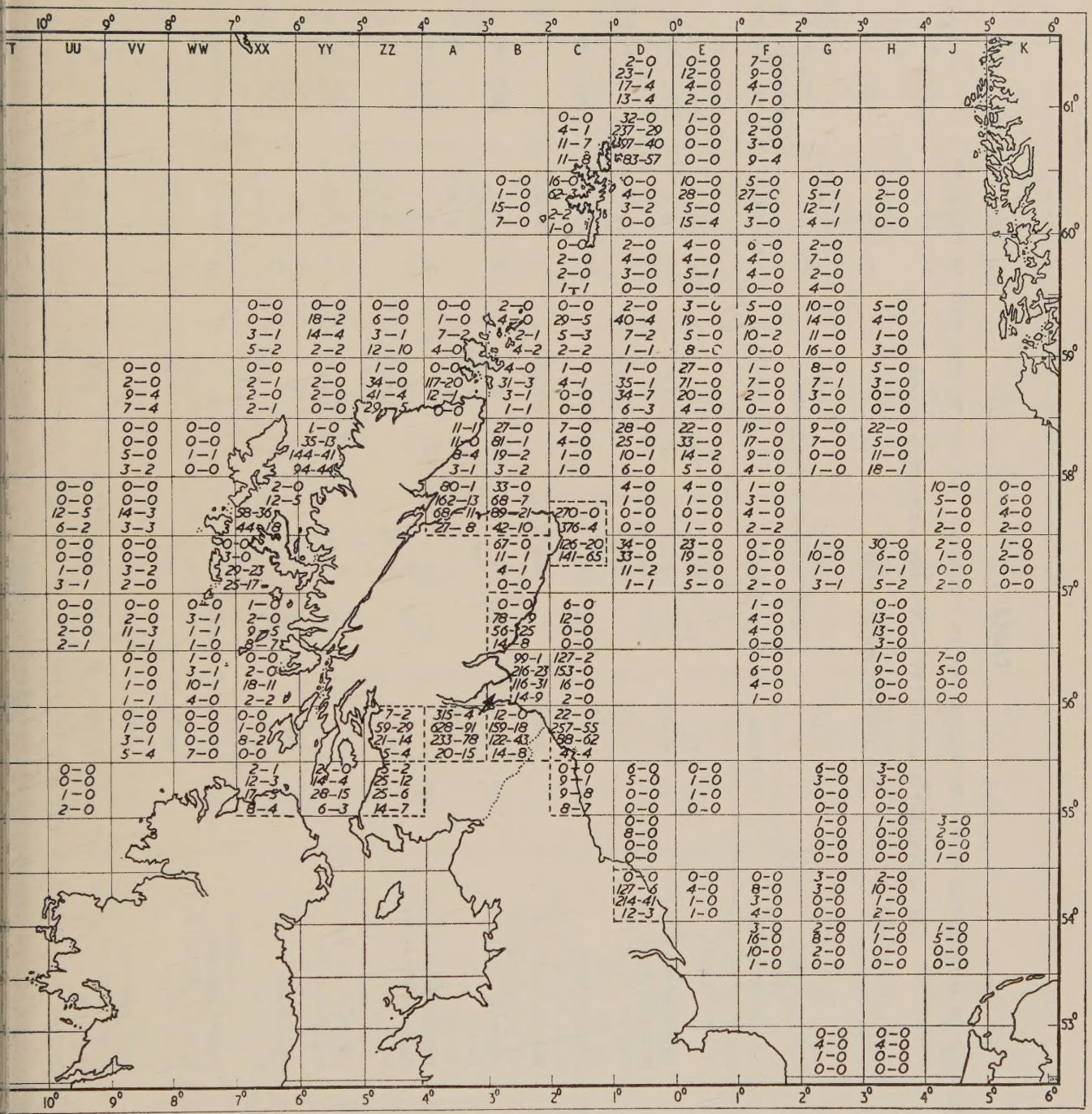

Fig. 1 Sampling of cod for nematode infestation of the flesh, 1958-1961.
Numbers of fish examined on left, numbers infested on right.
Size-groups from top of each rectangle to bottom (1) 11-30 cm (2) 31-50 cm (3) 51-70 cm (4) 71 cm and over.

TABLE I

FREQUENCY OF OCCURRENCE OF WORM-INFESTED COD IN THE NORTH SEA AND TO THE WEST OF SCOTLAND

No. = Number examined; W = Number with worms in flesh

July 1958-September 1961

Region or Locality	Years, Months of sampling	Length of cod in size groups								Total marketable cod i.e. 31 cm & over	
		11-30 cm		31-50 cm		51-70 cm		>70 cm			
		No.	W.	No.	W.	No.	W.	No.	W.	No.	W.
Inner Firth of Forth	1958-59-60-61 II, III, IV, V, VI, VII, VIII, IX, X, XI, XII	315	4	628	91	233	78	20	15	881	184
			1·3%		14·5%		33·5%		75·0%		20·9%
Angus Coast and Outer Firth of Forth	1958-59-60-61 II, III, IV, V, VI, VII, VIII, IX, X, XI, XII	99	1	294	32	172	56	28	17	494	105
			1·0%		10·9%		32·6%		60·7%		21·3%
East of Forth (C11, 12)	1958-59 VI, IX	133	2	165	0	16	0	2	0	183	0
			1·5%		0·0%		0·0%		0·0%		0·0%
St. Abbs to Farne Deep	1959-60-61 II, IV, V, VI, X, XI, XII	34	0	425	74	236	128	29	21	690	223
			0·0%		17·4%		54·2%		72·4%		32·3%
Yorkshire Coast	1960-61 I, II, X, XI, XII	—	—	127	6	214	41	12	3	353	50
			—		4·7%		19·2%		25·0%		14·2%
Southern North Sea (offshore)	1959-60-61 V, VIII, XI	41	0	122	0	40	0	13	0	175	0
			0·0%		0·0%		0·0%		0·0%		0·0%
Aberdeenshire Coast	1958-59-60-61 II, III, IV, V, VI, VIII, IX, X, XI, XII	371	0	420	5	141	23	142	66	703	94
			0·0%		1·2%		16·3%		46·5%		13·4%
Moray Firth	1958-59-60-61 II, III, V, VI, VII, VIII, IX, X, XI	151	2	322	20	184	38	75	21	581	79
			1·3%		6·2%		20·7%		28·0%		13·6%

TABLE I—*Continued*

FREQUENCY OF OCCURRENCE OF WORM-INFESTED COD IN THE NORTH SEA AND TO THE WEST OF SCOTLAND

No. = Number examined; W = Number with worms in flesh

July 1958-September 1961

Region or Locality	Years, Months of sampling	Length of cod in size groups								Total marketable cod i.e. 31 cm & over	
		11-30 cm		31-50 cm		51-70 cm		>70 cm			
		No.	W.	No.	W.	No.	W.	No.	W.	No.	W.
East Orkney	1958-59-60-61 III, IV, V, VI, VIII IX, X, XI	10	0 0·0%	143	14 9·8%	51	14 27·5%	14	9 64·3%	208	37 17·8%
East Shetland	1958-59-60-61 III, IV, V, VI, VIII, IX, XI, XII	36	0 0·0%	268	30 11·2%	120	46 38·3%	96	61 63·5%	484	137 28·3%
Northern North Sea	1958-59-60-61 III, IV, VI, VIII, IX, X, XI	282	0 0·0%	389	2 0·5%	167	8 4·8%	128	15 11·7%	684	25 3·7%
West Shetland	1958-59-60-61 VI, IX, X, XI	16	0 0·0%	69	4 5·8%	30	9 30·0%	20	9 45·0%	119	22 18·5%
North of Scotland	1958-59-60-61 III, VI, IX, X, XI, XII	1	0 0·0%	180	23 12·8%	84	13 15·5%	54	20 37·0%	318	56 17·6%
North Minch	1958-59-60-61 III, V, VI, VII, VIII, IX, XI	3	0 0·0%	47	18 38·3%	202	77 38·1%	138	62 44·9%	387	157 40·6%
W. of 7°W	1959-60-61 III, V, VI, VIII, XI	1	0 0·0%	12	2 16·7%	74	21 28·4%	47	19 40·4%	133	42 31·6%
South Minch to Northern Ireland	1958-59-60-61 III, V, VI, VII, VIII, XI	3	1 33·3%	20	3 15·0%	81	46 56·8%	43	30 69·8%	144	79 54·9%
Firth of Clyde	1959-60-61 III, IV, V, VII, XI	14	4 28·4%	98	45 45·9%	74	35 47·3%	25	14 56·0%	197	94 47·7%
All areas	1958-1961	1510	14 0·9%	3729	369 9·9%	2119	633 29·9%	886	382 43·1%	6734	1384 20·6%

size-range of the catch. In effect, therefore, the numbers in each size-group may be regarded as reasonably representative of the size composition in the various regions over the period. As sampling was more frequent in certain statistical rectangles than in others these have been considered separately to avoid influencing the results from neighbouring areas, which have been less intensively or extensively sampled. Records from the latter areas have been grouped according to their geographical position and on the basis of the frequency of the worm infestation (Table I and Figure 2).

Grateful acknowledgement is made to Dr. Z. Kabata for his confirmation of the identity of the worm parasites and to those members of the Marine Laboratory staff, among whom Mr. S. D. E. Devlin deserves special mention, who helped with the examination of the cod at sea and in the laboratory. The author also wishes to thank Dr. C. E. Lucas for his invaluable advice during the preparation of this paper.

SOME BIOLOGICAL FEATURES OF THE COD RELEVANT TO INFESTATION

Before examining the problem of worm infestation of cod it is pertinent to consider some biological features of this fish which are relevant to the present problem. Graham (1924) has shown that in the North Sea mature cod approach coastal waters, for example the vicinity of Flamborough Head and Aberdeen Bank, to spawn from January to April. Since the publication of Graham's paper, research has shown that cod spawn in other localities close to the Scottish coast, e.g. near the Bell Rock, in various inshore localities of the Moray Firth, off south-west Shetland, off the north coast of Scotland, in the east side of the North Minch from Cape Wrath to Skye, and in the Firth of Clyde. Mature cod do not all come inshore to spawn however. As Graham has shown, spawning also occurs in the North Sea on offshore banks such as the Fisher and Ling Banks. Owing to the incidence of these various spawning grounds and to the distributive action of the currents on the planktonic eggs and larvae young immature cod are found in varying concentrations throughout almost the entire North Sea. On the west of Scotland the situation is rather different. Here, there is apparently little or no offshore spawning and few young cod are found west of 7°W longitude.

After spawning the adult cod disperse to feed and to recover. Owing to the proximity of the different spawning concentrations, inshore areas on the Scottish east coast in general represent important nursery grounds for this species. Although these fish undoubtedly move about in search of food, there is no evidence that they take part in any extensive mass movements away from their nursery grounds until they are approaching first maturity. When this stage is reached, at 4, 5 or 6 years of age, the ripening fish join the adult fish on the neighbouring spawning grounds. After spawning, while some spent first-spawners may return to their nursery grounds to feed, others would appear to go further afield. The stocks of young cod up to about 4 or 5 years of age may, therefore, on the whole, be regarded as fairly stationary.

In comparison with many other food fishes the cod is a large, fast-growing species. It follows, therefore, that on any heavily fished grounds such a fish is likely to be fairly rapidly exploited. Although this tendency is to some extent offset by the cod's superior mobility and by its greater adaptability to varying ecological conditions, it is unfortunate that large cod are now less plentiful in the North Sea than they were at one time.

These observations may help towards an understanding of the numbers and distributions of the cod in the various size-groups in Figure 1. In the North Sea the stock consists predominantly of young fish of up to 50 cm in length. Although medium-sized fish (51-70 cm) are fairly well represented, large cod of 71 cm and over are relatively scarce in coastal areas, being less than 4% of all marketable-sized cod caught between the Farne Islands and the Firth of Forth and less than 10% between the Farnes and the north of Shetland. Only in the central part of the northern North Sea is this size-group reasonably well represented—19% of the marketable fish. On the west of Scotland, excluding the Firth of Clyde where young cod also predominate, the stocks, though much sparser than in the North Sea, include a greater proportion of large cod (34% of the marketable-sized fish).

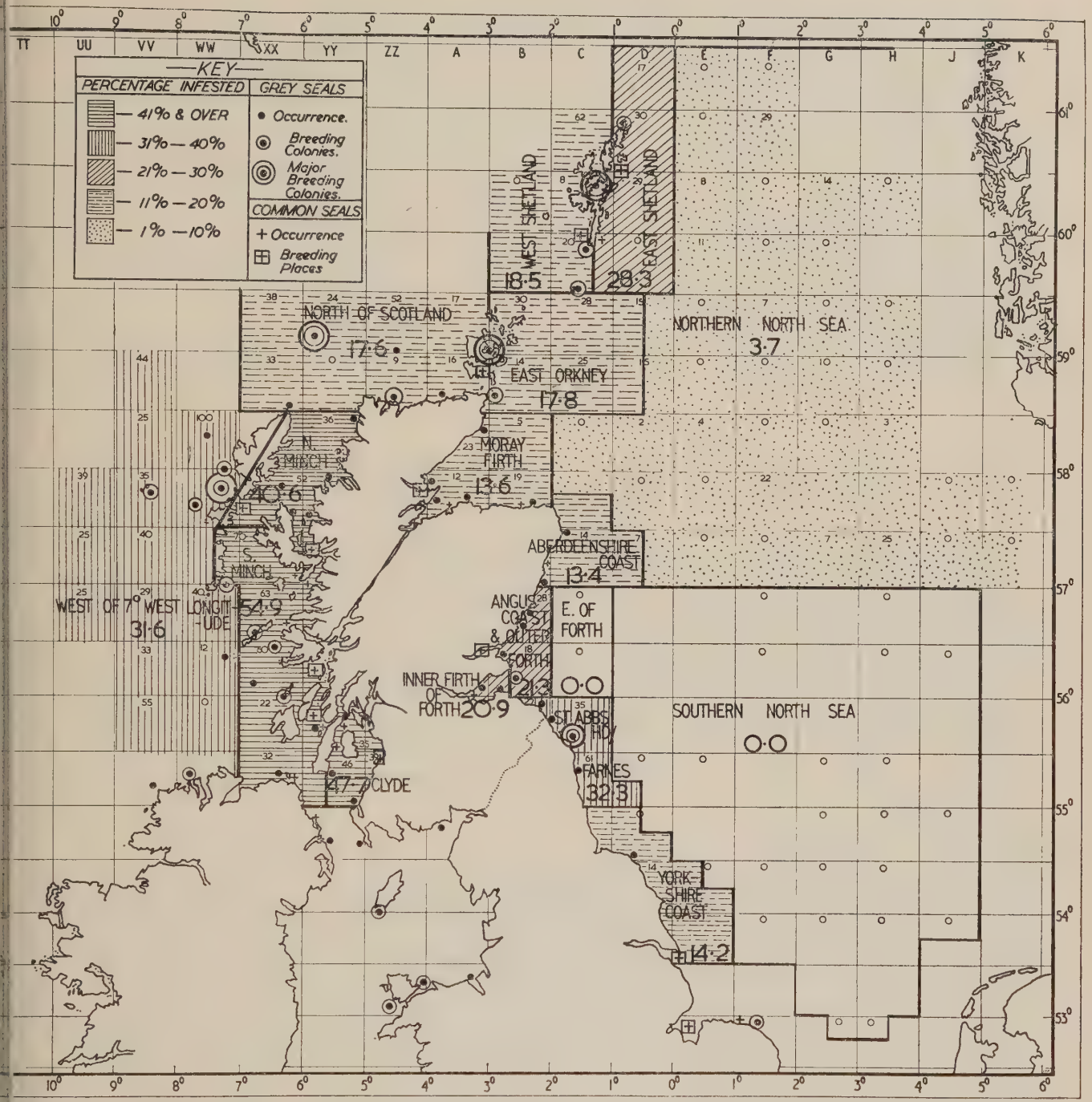

Fig. 2 Incidence of worm-infested cod and distribution of seals. Percentage of marketable-sized cod infested in each rectangle sampled (small numerals) and percentage in various localities or regions (large numerals).

IDENTIFICATION OF THE PARASITE

Although no attempt has been made throughout these investigations to identify every parasite found in the flesh of the cod, samples of worms have been preserved regularly for examination in the laboratory. This has revealed the presence of larvae of two worms—*Porrocaecum decipiens* and *Anisakis* sp. In order to determine the relative proportions of each parasite over 500 worms from a variety of samples were specially examined. Of these 88% proved to be *Porrocaecum decipiens*, 3% *Anisakis*, while the remaining worms, mainly small specimens, were not identified. These percentages confirm *Porrocaecum decipiens* as the dominant parasite in the flesh of cod in Scottish waters. All the worms at first identified by Scott and Martin (1957), from eastern Canada proved to be *Porrocaecum*, although later the same workers (Scott and Martin, 1959) found the parasites to consist of 97% *Porrocaecum* and 3% *Anisakis*. The present investigations have also shown that in Scottish waters the small proportion of *Anisakis* is variable from place to place and that in some localities this parasite would appear to be absent, as Grainger (1959) found off the west coast of Scotland.

The lengths of 546 worms from cod taken in different localities ranged from 11 to 55 mm. The average length was 33·5 mm and rather more than half of the worms were from 30 to 40 mm. These results are in fairly close agreement with those obtained by Templeman *et al* (1957) whose measurements ranged from 13 to 58 mm with an average size of 36·9 mm.

FREQUENCY OF OCCURRENCE OF WORM-INFESTED COD

Table I shows the frequency of worm infestation of the flesh of cod in the North Sea and on western grounds. The second column gives the years and the months in which the various localities and regions were sampled. Inshore grounds on the Scottish east coast have naturally received most attention because of their proximity to the laboratory in Aberdeen and because it was from these grounds that the first indications were obtained of the extent of the cod worm problem in the north-western North Sea. Sampling of these grounds from the Moray Firth to Berwick-upon-Tweed has been carried out each year since 1958 and at all seasons. Although other localities or regions have been less regularly sampled the time and frequency of their sampling have, on the whole, provided records which are broadly comparable. Columns 3 to 6 give the numbers of cod examined in each size-group with the numbers and percentages of the fish affected, and column 7 summarises the figures for all marketable-sized fish, i.e. totalling columns 4, 5 and 6.

Size-group 11 to 30 cm

In the smallest size-group, 11-30 cm, comprising cod below the minimum marketable size, few of the fish were affected with worms. In a grand total of 8244 cod of all sizes examined during these investigations from July 1958 to September 1961, more than 1500 were from 11 to 30 cm in length, yet nematodes were found in the flesh of only 14 of these fish. Four of these were caught in the Firth of Forth, three outside the Firth of Forth, two in the Moray Firth, four in the Firth of Clyde and one off the north coast of Ireland. Only 21 fish of this size were examined from the Clyde and other western grounds, so that it seems possible that small cod may be more seriously parasitised there than in the North Sea. This statement finds some support from a study of the degree of infestation of the 14 infested fish; each of the nine codling from the Firth of Forth and Moray Firth areas contained only a single worm, while of the five west coast fish two contained 1 worm, one 2 worms, one 3 worms and one 4 worms.

These differences in the frequency and degree of infestation of the small cod of eastern and western Scottish grounds might arise from some biological difference in the codling of the two regions, for example, from different growth rates or, more probably, from a higher risk of infestation in western waters.

At the same time it should be remembered that these investigations were concerned only with visible worms and it is, therefore, possible that many of the small cod in the various localities may have been parasitised by a younger stage of the worm not readily visible to the naked eye.

Size-group 31 to 50 cm

In the 31-50 cm size-group more than 3,700 fish were examined. Of these 369 (10%) were infested in some degree. With the exception of two fish, one of 46 cm caught on the Viking Bank in June 1961 and the other of 42 cm taken in the Coral Bank area in September of the same year, the infested fish in this size-group were all from coastal waters within a distance of 30 miles (usually much less) from the coast. Beyond 30 miles from the coast and throughout the North Sea from latitude 52°45′N northwards to latitude 61°30′N nearly 700 cod of this size-group were examined but only the two fish referred to above were found to be parasitised, each by only one worm (Fig. 1).

Table I shows that the numbers of infested cod in this size-group varied from one section of the coast to another. Infestation was heaviest on the west coast, particularly in the Firth of Clyde and in parts of the Minch where from 38 to 46% of the fish were affected. From 10 to 18% of the fish in this size-group were affected in other Scottish coastal waters, including parts of the west and north of Scotland, the east sides of Orkney and Shetland and from the coast of Angus and Firth of Forth southwards to the Farne Islands. Infestation occurred in 6% or less of the fish on the west side of Shetland, in the Moray Firth and on the Yorkshire coast (records from 1960 and 1961 only) while only 1% was affected off the Aberdeenshire coast.

Size-group 51 to 70 cm

In the 51-70 cm size-group, consisting of adolescent and adult cod mainly 5 to 6 years of age, over 1000 fish were examined of which 633 (30%) were worm-infested in greater or less degree. This shows a marked increase in the numbers of infested fish compared with the 31-50 cm size-group. In general, the more heavily affected areas were the same as in the previous group. In some western localities, notably in the inner Firth of Clyde, in parts of the Minch and on the east coast between the Farne Islands and St. Abbs Head, more than half of the cod of 51-70 cm were worm-infested. A relatively high frequency of infestation, from 25 to 40%, was obtained on other west coast grounds, both inshore and offshore, around the Orkneys and Shetlands and in the Firth of Forth area. Relatively light infestation of this size-group occurred off the north of Scotland, in the Moray Firth, off Aberdeenshire, off Yorkshire and in the offshore regions of the northern North Sea. Worm-free fish in this size-group occurred in only two areas—the offshore southern North Sea and a small rectangle east of the Firth of Forth—in each of which, however, few cod of this size were examined.

Size-group 71 cm and over

As already indicated, adult cod of 71 cm and over are now scarcer in the North Sea, particularly in Scottish coastal areas, than formerly. Rather fewer than 900 fish in this category were examined in the present investigations. Of these 43% were infested. As in the smaller fish, infestation was heaviest off south-west Scotland, but a marked increase in the proportions of infested fish was observed in coastal areas from the Firth of Forth to the Farne Islands (60 to 75%), and an increase in the numbers of parasitised cod was noted in all areas compared with previous size-groups. Worm-infested adult cod were found in all the regions listed in Table I with the exception of the southern North Sea (outside coastal waters) where, however, few fish of this size were examined.

These results may be summarised as follows:—

1. infestation of North Sea cod below the minimum marketable size of 30 cm is negligible, but there is some evidence that infestation of this group may be appreciable in some localities of western Scotland;
2. the number of infested fish increases through the various size-groups, i.e. with growth and age, to a maximum in cod of 71 cm and over;
3. infestation varies from one region or locality to another;
4. infestation is heavier in Scottish coastal waters than offshore;
5. in general, infestation is heavier on the west of Scotland than in the North Sea;
6. local variations in the overall frequency of infestation may, to some extent, result from differences in the age composition of the fish on the grounds.

THE DEGREE OF INFESTATION

Number of Worms per Infested Fish

The degree or intensity of infestation has been studied by considering the numbers of worms occurring in each infested fish. The results, summarised in Table II, show that the proportion of cod containing only one worm amounts to 61% in the 31-50 cm size-group and that this falls to 43% in the 51-70 cm group and to 28% in fish of 71 cm and over.

TABLE II

DEGREE OF INFESTATION OF COD BY NEMATODE LARVAE
NORTH SEA AND WEST OF SCOTLAND GROUNDS, 1958-1961

Size-group		No. (and %) of infested fish containing the following no. of worms												No. of infested fish examined
		1	2	3	4	5	6	7	8	9	10	11–20	>20	
31-50 cm	No.	227	77	24	16	10	4	3	1	2	1	2	3	370
	%	61	21	7	4	3	1	1	+	+	+	+	1	
51-70 cm	No.	270	128	61	39	33	16	14	8	9	5	28	22	633
	%	43	20	10	6	5	2	2	1	1	1	5	4	
71-110 cm	No.	108	79	54	31	20	12	6	10	9	8	32	13	382
	%	28	21	14	8	5	3	2	3	2	2	8	3	

Although in each size-group the percentage of the fish containing two worms would seem to remain almost constant (20 to 21%) the numbers containing three or more worms in each size-group increase with the size of the fish, so that the proportions containing ten or more worms rise from a little over 1% in the 31-50 cm group to 10% at 51-70 cm and to over 13% among the large cod of 71 cm and over.

The same data have also been examined on regional and yearly bases (Table III). For this purpose the records have been grouped in three main geographical regions. In each of the three regions the degree of infestation increases with the size and age of the fish. Table III also indicates the overall higher degree of infestation on west coast grounds than in either the Orkney, Shetland and north coast region or the North Sea. An increase in the degree of infestation is also noticeable from 1958-59 to 1961; this is particularly apparent in the North Sea. It must be concluded that the degree of infestation tends to increase in proportion to the numbers of fish affected on the various grounds and also with the size and age of the fish.

Although from 71 to 93% of the infested cod (depending on the size of the fish) contained from one to four worms and the proportions containing five or more worms were, in general, relatively small, a few of the fish recorded as containing twenty-one or more worms proved to be very heavily infested, by anything from 50 to 100 worms. This excessive infestation of a few fish has already been observed in cod by Kahl (1939), and a similar feature has been noted by Rae (1958) in the infestation of halibut by larvae of the cestode *Grillotia erinaceus*.

Number of Worms per Unit Weight of Fillets

The intensity of infestation may, however, be considered from another angle—namely, the numbers of worms per unit weight of edible fish flesh. For this purpose samples of inshore cod, obtained from commercial sources and from research vessels in 1961, have received special treatment. This has included the block-filleting of the fish and the noting of the worm content of the fillets, which were also weighed. In this way the number of worms per 100 lb (45 kg) of fillets, including all infested and non-infested fish,

TABLE III

DEGREE OF INFESTATION OF COD BY NEMATODE LARVAE, 1958-1961

NORTH SEA, SOUTH OF 58°30'N

Size Group	Year	No. Infested Fish	No. and % of fish containing the following no. of worms: 1	2	3	4	5	6	7	8	9	10	11–20	>20
31-50 cm	1958-59	56	43	7	3	1	1	—	—	—	—	—	—	1
		%	77	12	5	2	2	—	—	—	—	—	—	2
	1960	88	58	24	4	1	—	—	1	—	—	—	—	—
		%	66	27	5	1	—	—	1	—	—	—	—	—
	1961	85	48	17	5	4	4	1	2	1	1	—	—	2
		%	56	20	6	5	5	1	2	1	1	—	—	2
	1958-61	229	149	48	12	6	5	1	3	1	1	—	—	3
		%	65	21	5	3	2	+	1	+	+	—	—	1
51-70 cm	1958-59	83	45	23	9	1	1	—	2	—	—	—	2	—
		%	54	28	11	1	1	—	2	—	—	—	2	—
	1960	93	45	23	12	7	3	—	1	1	—	—	1	—
		%	48	25	13	8	3	—	1	1	—	—	1	—
	1961	192	65	28	19	17	13	6	6	4	6	3	11	14
		%	34	15	10	9	7	3	3	2	3	1	6	7
	1958-61	368	155	74	40	25	17	6	9	5	6	3	14	14
		%	42	20	11	7	5	2	2	1	1	1	4	4
71-110 cm	1958-59	18	9	4	2	1	—	—	—	—	—	—	2	—
		%	50	22	11	6	—	—	—	—	—	—	11	—
	1960	30	9	7	5	3	—	—	—	1	1	1	3	—
		%	30	23	17	10	—	—	—	3	3	3	10	—
	1961	101	32	17	15	4	14	1	—	3	3	1	10	1
		%	31	17	15	4	14	1	—	3	3	1	10	1
	1958-61	149	50	28	22	8	14	1	—	4	4	2	15	1
		%	34	19	15	5	9	1	—	3	3	1	10	+

TABLE III—*Continued*

DEGREE OF INFESTATION OF COD BY NEMATODE LARVAE, 1958-1961

ORKNEY, SHETLAND, NORTH OF SCOTLAND

Size Group	Year	No. Infested Fish	No. and % of fish containing the following no. of worms											
			1	2	3	4	5	6	7	8	9	10	11–20	>20
31-50 cm	1958-59	27	15	7	2	1	—	1	—	—	1	—	—	—
		%	55	26	7	4	—	4	—	—	4	—	—	—
	1960	27	16	5	2	3	—	1	—	—	—	—	—	—
		%	59	19	7	11	—	4	—	—	—	—	—	—
	1961	19	14	2	1	—	2	—	—	—	—	—	—	—
		%	74	11	5	—	10	—	—	—	—	—	—	—
	1958-61	73	45	14	5	4	2	2	—	—	1	—	—	—
		%	62	19	7	5	3	3	—	—	1	—	—	—
51-70 cm	1958-59	35	20	8	2	1	—	—	3	—	—	—	—	1
		%	57	23	6	3	—	—	8	—	—	—	—	3
	1960	9	5	1	1	—	1	—	—	—	—	—	—	1
		%	56	11	11	—	11	—	—	—	—	—	—	11
	1961	42	20	11	1	—	1	2	2	1	—	1	2	1
		%	48	26	2	—	2	5	5	2	—	2	5	2
	1958-61	86	45	20	4	1	2	2	5	1	—	1	2	3
		%	52	23	5	1	2	2	6	1	—	1	2	4
71-110 cm	1958-59	30	10	6	5	—	—	1	1	1	—	2	3	1
		%	33	20	17	—	—	3	3	3	—	7	10	3
	1960	27	9	6	4	2	1	1	—	—	1	2	1	—
		%	33	22	15	7	4	4	—	—	4	7	4	—
	1961	51	5	13	9	7	3	1	2	2	—	—	5	4
		%	10	25	18	14	6	2	4	4	—	—	9	8
	1958-61	108	24	25	18	9	4	3	3	3	1	4	9	5
		%	22	23	17	8	4	3	3	2	1	4	8	5

TABLE III—*Continued*

DEGREE OF INFESTATION OF COD BY NEMATODE LARVAE, 1958-1961

WEST OF SCOTLAND

Size Group	Year	No. Infested Fish	No. and % of fish containing the following no. of worms											
			1	2	3	4	5	6	7	8	9	10	11–20	>20
31-50 cm	1958-59	30	12	9	4	3	1	—	—	—	—	—	1	—
		%	40	30	13	10	3	—	—	—	—	—	3	—
	1960	21	13	1	3	1	2	—	—	—	—	1	—	—
		%	62	5	13	5	10	—	—	—	—	5	—	—
	1961	17	8	5	—	2	—	1	—	—	—	—	1	—
		%	47	29	—	12	—	6	—	—	—	—	6	—
	1958-61	68	33	15	7	6	3	1	—	—	—	1	2	—
		%	49	22	10	9	4	1	—	—	—	1	3	—
51-70 cm	1958-59	63	24	14	6	5	5	3	—	1	2	—	2	1
		%	38	22	9	8	8	5	—	2	3	—	3	2
	1960	44	21	3	2	5	4	1	—	1	—	—	5	2
		%	48	7	5	11	9	2	—	2	—	—	11	5
	1961	72	25	17	9	3	5	4	—	—	1	1	5	2
		%	35	24	13	4	7	5	—	—	1	1	7	3
	1958-61	179	70	34	17	13	14	8	—	2	3	1	12	5
		%	39	19	9	7	8	4	—	1	2	1	7	3
71-110 cm	1958-59	64	17	13	9	5	1	5	2	1	3	1	2	5
		%	26	20	14	8	2	8	3	2	5	1	3	8
	1960	34	14	7	3	5	—	1	1	1	1	—	1	—
		%	41	20	9	15	—	3	3	3	3	—	3	—
	1961	27	3	6	2	2	3	2	—	1	—	1	5	2
		%	11	22	8	7	11	7	—	4	—	4	19	7
	1958-61	125	34	26	14	12	4	8	3	3	4	2	8	7
		%	27	21	11	10	3	6	2	2	3	2	6	6

has been calculated. It should be noted that in filleting the cod the "lugs" or "flaps" were removed so that worms in these parts have not been included in the calculations. The results are given in Table IV.

Once more the variable nature of the infestation is evident in the different localities and within each size-group. In each of the six localities investigated infestation, as expected, is heavier per unit weight of fillets in the 51-70 cm group than in the 31-50 cm group. In the 71 cm and over size-group, however, despite the greater percentage frequency of infested fish (Table I), the number of worms per 100 lb of fillets in each locality is lower than in the 51-70 cm group (Table IV). This feature, which has also been

TABLE IV

INFESTATION OF COD BY LARVAL NEMATODES

NUMBER OF WORMS PER 100 LB (45 KG) OF FILLETS

Locality	Date	Size group cm	No. of cod examined	% infested	Wt of fillets lb	No. of worms in fillets	No. of worms per 100 lb fillets
Yorkshire coast	February, 1961	31-50	7	0·0	5·5	0	0
		51-70	19	31·6	31·7	5	16
		71-79	4	0·0	11·3	0	0
Farne Islands	April, May, June, 1961	31-50	238	22·3	126·8	132	104
		51-70	92	70·7	119·9	555	463
		71-84	10	90·0	30·0	87	290
East of Firths of Forth and Tay	Feb., Mar., 1961	31-50	37	10·8	28·8	4	14
		51-70	56	44·6	80·2	25	31
		71-86	14	57·1	40·1	12	30
Aberdeenshire coast	Aug., Sept., 1961	31-50	99	2·1	48·8	2	4
		51-70	43	18·5	66·3	16	24
		71-105	52	55·5	256·1	26	10
Moray Firth	May, June, 1961	31-50	55	9·1	29·6	8	27
		51-70	20	50·0	30·9	54	175
Minch, off Skye	Feb., Mar., 1961	51-70	25	80·0	43·3	78	180
		71-95	7	100·0	21·1	19	90

observed by the Canadians, would seem to suggest that the rate of infestation does not keep pace with the rate of growth in the weight of the fish. At the same time it is possible that the gradual change in the food of cod which accompanies increase in size (for example the changeover from crustaceans to fish) may have some effect, if the diet of the bigger fish were to include a smaller proportion of the organisms which act as the first intermediate host, or of those serving as transporters or carriers of the parasite in its early stages.

There is also the possibility that the greater migrational movement of adult cod, known to take place from the results of traditional cod fisheries on the Scottish coast, may in some measure account for this phenomenon. Thus, big fish native to offshore areas, where infestation is slight or even non-existent, moving into coastal waters, where infestation is appreciably greater, will tend to lower the degree of infestation as measured by the number of worms per unit weight of fillets. On the other hand the same effect may be produced by some coastal cod, on reaching maturity, leaving their native areas, where infestation is appreciable, and returning after an interval spent offshore. Infestation in such fish might be less than in those of the same age and size which remain on or near their native grounds.

Kahl (1939) found Iceland cod to be more heavily infested with *Porrocaecum decipiens* than those from any other region he investigated. Even so, he found that only 9·4% of all sizes of cod were affected at Iceland, as compared with 5·2% in the North Sea. Kahl also found the Icelandic level of infestation to be 6·9 worms per 100 lb of fillets. Although he gave no corresponding figure for North Sea cod it may perhaps be assumed that he considered it was lower than at Iceland. It would appear, therefore, that the degree of infestation of cod by *Porrocaecum* in Scottish coastal waters found in 1961, as shown in Table IV, is considerably greater than Kahl's calculation for unknown North Sea grounds in the late 1930s.

In eastern Canada, Templeman *et al* (1957) found infestations varying up to a maximum of 223 nematodes per 100 lb of cod fillets, while Scott and Martin (1957) experienced infestations equivalent to 400 nematodes or more per 100 lb of fillets. Although the Canadian calculations were based on the examination of a far larger number of cod, the Scottish results in Table IV suggest that, at least in certain localities, the infestation is as heavy as in some parts of eastern Canada, and the remarkable figures obtained from a series of nine commercial samples from the vicinity of the Farne Islands in the spring and early summer of 1961 suggest that in this locality it may even be heavier.

Distribution of Worms in the Body of the Fish

Another feature of worm infestation may now be considered. This concerns the location of the worms in the muscles of the fish. In a total of nearly 5,000 worms 87% were located in the ventral half of the fish, i.e. from the lateral line downwards, and 12% in the dorsal parts above the lateral line from the head backwards to the tail. In the ventral half, 53% of the grand total were located on the left side and 34% on the right. Dorsally, 5% of the worms were on the left side and 7% on the right. These results, which in general confirm earlier unpublished records by Dr. G. H. O. Burgess of the Department of Scientific and Industrial Research Laboratory, Hull, show that most of the worms were located in the flesh surrounding the body cavity. A somewhat similar distribution of the worms has also been demonstrated by Templeman and others (1957). In the present investigation about 45% of the worms were found in or near the inferior flesh enclosing the body cavity, known after gutting to British fishermen and fish merchants as the "lugs" or "flaps". This percentage, however, varies from place to place and probably also from time to time; for example it has been found to be as low as 7% in a sample from the west of Orkney and as high as 63% on the Yorkshire coast. Moreover, owing to the position of the bulk of the worms the percentage attributed to the flaps and lugs is likely to depend to some extent on the skill of the individual filleter.

By removing these less valuable parts of the fish, therefore, merchants can eliminate nearly half of the worm load and by a further trimming of the flesh adjoining these parts, an even higher proportion of the parasites may be eliminated. Cutting and Burgess (1960), dealing with cod from different parts of the North Atlantic, have estimated that 80% of the worms may be eliminated by dressing the fillets.

As the remaining parasites may be located at any point in the flesh of the fish this constitutes a problem for fish merchants, who are faced with the prospect of removing them before offering the fish for sale. This may be done by filleting and by removing the worms thus exposed and by candling the fillets so at to reveal deep-seated worms, but in spite of these precautions there remains a possibility that some worms in the thicker parts of the fillets may still escape detection (Power, 1957, 1961).

The concentration of the parasites in the flesh surrounding the body cavity is further proof of the view expressed by Baylis (1916) that infestation is acquired through the food and by the penetration of the stomach wall and peritoneal tissue by the embryonic worms.

HISTORICAL ACCOUNT OF THE OCCURRENCE OF *PORROCAECUM DECIPIENS* IN COD OF THE NORTH SEA AND ADJACENT WATERS

At this stage it is of interest to examine the historical aspect of the problem in the north-east Atlantic with a view to studying the position in the recent past. References to the occurrence of this parasite in scientific literature have, therefore, been summarised in the following paragraphs.

Baylis (1916) concluded that a common nematode parasite of fishes, *Ascaris capsularia* Rudolphi, was in fact the larval form of *Ascaris decipiens* Krabbe, a well-known parasite of seals. The worms examined by Baylis were from the peritoneal tissues of marine fishes and, although cod was included in his list of fish hosts, he made no reference to having found worms in the muscle tissues of that fish. Later, the same author (1920), in a reclassification of the Ascaridae, referred this worm to the genus *Porrocaecum*.

After a brief reference to the occurrence of nematodes in the muscles of a cod from an unknown source in 1910, Williamson in 1919 described the presence of "coiled nematodes scattered singly through the muscles" of codlings from Faeroe, Rona and Rockall. In his experience, codling from Faeroe were particularly affected and he concluded by stating—"At present it is believed they (the worms) do not occur in North Sea (including Shetland waters) fish". The worms described by Williamson resembled the larval form of *Ascaris decipiens*, adult specimens of which he had previously found "in profusion in the alimentary tract of two species of seal."

Johnstone *et al* (1924) list a number of nematodes found in the peritoneal tissues and alimentary canal of cod but, except for a brief reference to Williamson's single record of 1910, no mention is made in their paper of *Porrocaecum* or of any other nematode in the musculature of this fish. It must, therefore, be concluded that Johnstone, who had ample opportunities of observing all kinds of fish parasites and who wrote extensively on the subject, had no experience of this particular worm infestation from the western grounds from which he derived most of his specimens. This seems all the more significant when one recalls Johnstone's close association with those responsible for the inspection of fish landed in north-west England.

Martin (1921) recorded the occurrence of larval specimens of *Ascaris decipiens* in the flesh of a codling caught in the Baltic in 1918. In the same paper he also referred to the presence of this worm in the flesh of smelts (*Osmerus eperlanus*). Martin confirmed Baylis's conclusions that *Ascaris capsularia* is the larval form of *Ascaris decipiens*.

Wulker (1929, 1930 a and b) examined many nematodes from the alimentary canal and peritoneal tissues of North Sea fishes but, except for a brief reference to an early description by Linstow of the occurrence of *Ascaris eperlani* (the *Ascaris decipiens* of Martin) in the muscles of the smelt, he had little to add to the subject of worm infestation of the flesh of fish.

During the 1920s and 1930s representations regarding the presence of nematodes in the flesh of fish, mostly cod, were made on a number of occasions to the Fishery Board for Scotland by members of the fish trade and by private individuals. Some of these minor complaints and problems were investigated intermittently and on a modest scale by the author, who, in addition to questioning merchants, fishermen and fishery officers on the subject, had frequent opportunities of examining the flesh of numerous fish, including cod, filleted on board the research vessel 'Explorer'. During these years it became clear that wormy cod were not uncommon in certain localities on the west coast of Scotland and at Shetland. There was, however, at that time no indication that this form of infestation attained any great proportion in Scottish waters or that it was regarded with disquiet by any section of the industry. Although the cod was the species most frequently referred to in connection with worm infestation of the flesh, saithe and tusk were also affected and on very rare occasions nematodes were also found in the muscle tissues of haddock, whiting, lythe (pollack), hake, ling, conger-eel, plaice and lemon sole caught off the coasts of Scotland. The author was at that time unable to identify these larval nematodes with any degree of certainty; nevertheless, those found in gadoid fishes were recognised as resembling the *Ascaris decipiens* identified by Williamson in 1919.

Kahl (1938) described the appearance of nematode worms in the flesh and in other parts of various species of fish. Later (1939) the same writer calculated the percentages of cod and other species showing infestation of the flesh by larvae of *Porrocaecum decipiens* from different fishing regions in the north-east Atlantic, and for the first time this parasite was recorded in some concentration from the flesh of North Sea cod. In Icelandic waters 9·4% of the cod were thus infested, in the North Sea 5·2%, while smaller proportions were affected off the northern Norwegian coast, in the Barents Sea and in the Baltic. Kahl also distinguished between the sizes of the infested cod. From the North Sea he examined a total of 964 fish with the results shown in Table V. Unfortunately he did not give the locality or localities in the North Sea from which his cod were obtained, nor did he indicate whether the numbers examined in

each of the three size-groups were in their natural proportions. It is, however, interesting to note that Kahl found infestation increasing with the size of the fish and that in the smallest fish, up to 60 cm in length, not a single cod was affected. These results should be compared with those for infested fish in the 31-50 cm size-group of Table I. Similarly, the frequency of infestation in Kahl's 60-80 cm and over 80 cm size-groups should be studied in conjunction with the 51-70 cm and 71 cm and over size-groups of Table I.

Punt (1941) examined numerous nematodes, mainly from the stomach and intestines of North Sea fish, but was not concerned with larvae of *Porrocaecum* which, he stated, prefer the muscular tissues of fish.

TABLE V

PORROCAECUM LARVAE IN THE FLESH OF NORTH SEA COD (KAHL, 1939)

Size Group	up to 60 cm	60-80 cm	over 80 cm	Totals
No. of cod examined	200	522	242	964
No. infested	0	9	41	50
% infested	0·0	1·7	16·9	5·2

Although Baylis (1916) apparently had no personal experience of the occurrence of *Porrocaecum* in the muscles of cod, later (Baylis, 1944) he referred to the extremely common occurrence of nematode larvae in the intermuscular connective tissue as well as in the sub-peritoneal tissues of fish off the British coasts. On this occasion he distinguished between *Porrocaecum* and *Anisakis* but pointed out that in their younger stages the two worms are indistinguishable. Baylis also quoted Rudolphi (1809) as stating that *Ascaris capsularia* had been found in salmon.

Following the Second Great War, enquiries from the fish trade, from Medical Officers of Health, from hospital authorities and from others regarding worm infestation began to reach the Marine Laboratory of the Scottish Home Department more frequently than at any time in the past. At the same time similar enquiries were being addressed to the Torry Research Station of the Department of Scientific and Industrial Research at Aberdeen, and to its subsidiary station at Hull where the problem was investigated by Dr. G. H. O. Burgess. Although some of these enquiries concerned fish from distant waters a growing number related to the North Sea and other home waters.

About this time Daniel (1950) wrote "the larvae of nematodes may also be found in the flesh of commercial fish. The adult stage *Porrocaecum decipiens* (Krabbe, 1878) is found in seals, and larvae are found in the flesh of the smelt and in about 4% of the cod from various fishing grounds".

Dollfus (1953), in his monograph on the parasites of the cod, dealt with *Porrocaecum decipiens* and its synonyms in detail.

In view of the growing interest and some slight disquiet of the fish trade in the United Kingdom on the subject of worm infestation, the author in 1955 prepared a note on "Parasites in Fish" which was widely circulated throughout the trade. This note provided a brief summary of the subject, referring among other things to the "rather high nematode infestation of the flesh of cod from certain inshore localities on the west of Scotland, at Shetland, at the Faroes and at Iceland".

At this point it is perhaps appropriate to refer to what had been taking place in a region adjoining the North Sea. Agersborg (1918) recorded a heavy worm-infestation of fish in coastal waters of northern Norway in 1917. In addition to being present in the organs of the body cavity the parasites were also found in the muscles of cod and saithe in such quantities as to make many of these fish unfit for human food. Worm infestation of the flesh of cod and saithe was practically unknown at the beginning of the century in that region and Agersborg noted that "it may be fair to assume that the attack of nematodes on marketable fishes in Norway may become an economic problem".

Forty years later, Berland (1958), after referring to Agersborg's observations, concluded that the worms in the muscles of the cod and saithe were the larvae of *Porrocaecum decipiens* and correlated the

infestation in 1917 with an abnormally heavy invasion of northern Norwegian coastal waters by the Greenland or harp seal, *Phoca groenlandica* Fabricius in 1916 and 1917. Reviewing infestation by *Porrocaecum,* Berland (1961) drew attention to the apparent correlation between the numbers of seals present in an area and the rate of infestation of fish by *P. decipiens* larvae. Although he also referred to other "seal" years on the Norwegian Coast in which no exceptional infestation of fish was observed, it may be that in these years either the infestation was allowed to pass unrecorded or the seal invasions were of insufficient magnitude or duration to have any noticeable effect on the worm infestation of the fish stocks.

Throughout the years, worm infestation of cod flesh in northern Norwegian waters has never attained the proportions experienced on the east coast of Canada. This has been attributed by Berland to the comparatively small seal population of the Norwegian coast where the numbers of these animals are kept in check by shooting.

Following recent references by Norwegian naturalists to the decline of the seal population in Norway and to the need for protective measures, Vik (1959), while agreeing with the basic aims of nature conservation, recalled the dangers of permitting any increase in the number of seals, both from the point of view of worm infestation of marketable fish and from the wider aspect of fish conservation in general.

EVIDENCE OF AN INCREASE IN THE INFESTATION

Despite the absence of earlier records of cod-worm infestation directly comparable with those obtained in the last four years, it would appear from the review of relevant literature that, in the past, larvae of *Porrocaecum decipiens* were at least much scarcer in cod from Scottish waters than at present. From the time of the first report of the presence of the parasite in cod from north-west Scotland by Williamson (1919), however, there appears to have been an increase in its infestation of this species round the Scottish coast. It also seems clear that this development started on the west coast and had attained considerable proportions before Scottish east coast grounds were obviously affected. For example, between the two wars cod from certain western localities were already known to be extensively parasitised, while in the same period worm-infested fish were still extremely rare in coastal waters of the north-western North Sea. The position at the present time, therefore, reflects a remarkable growth in this infestation since the inter-war period. Moreover, from the numbers of reports of worm infestation of cod received from fish merchants and others by the Scottish Home Department, later the Department of Agriculture and Fisheries for Scotland, it would appear that the infestation has been increasing.

TABLE VI

PROPORTIONS OF WORM-INFESTED FISH AMONG COD OF MARKETABLE SIZE
(31 CM and OVER)

July 1958-September 1961

No. = Number of cod examined; % = percentage infested

Area	1958		1959		1960		1961	
	No.	%	No.	%	No.	%	No.	%
St. Abbs Head—Farne Is.	—	—	305	23·7	23	26·1	362	39·8
Firth of Forth	75	5·3	188	12·8	498	23·3	120	33·3
Outer Firth of Forth	55	9·1	107	18·7	162	20·4	170	27·6
Aberdeenshire coast	80	0·0	93	3·2	190	4·2	340	24·4
Moray Firth	21	23·8	194	10·8	154	7·1	212	19·8
Orkney—Shetland—north coast	129	13·2	328	22·9	396	13·6	276	38·4
Northern North Sea (offshore)	147	0·7	18	0·0	278	4·3	247	4·9
West of Scotland	—	—	368	43·0	297	46·0	242	47·9

In order to examine this aspect of the problem in more detail Table VI has been prepared to show he percentages of infested fish among cod of marketable size in various localities or regions for each ear from 1958 to 1961. For comparative purposes sampling must be carried out regularly and on approximately the same grounds throughout each year. These conditions have been satisfied by records om the first four localities—from the Farne Islands northwards to the Aberdeenshire coast. In each of ese localities the proportion of worm-infested fish shows a steady rise over the period under review.

Although substantial numbers of fish were examined in the remaining four regions of Table VI over ie greater part of the period, sampling in these regions, each of which is considerably greater in area ian any of the first four localities, has on the whole been less regular, both in time and in place, so iat results are not as suitable for comparison from year to year and accordingly cannot be regarded as aving the same significance. Nevertheless, the results may be regarded as representative in a general ense.

In the northern North Sea, where the average infestation is low, a slight but appreciable rise in the umbers of worm-infested cod is evident from 1958 and 1959 to 1960 and 1961. In the Moray Firth nd in the Orkney-Shetland-north coast region, the percentages of infested fish fluctuate from year to ear. On the west of Scotland infestation would appear to have reached considerable proportions prior o the start of these investigations, and to have remained fairly stable throughout the period of the mpling.

The examination of individual samples of cod from different grounds has shown that the entry of new brood into the fishable stocks may occasionally cause the proportion of infested fish to vary from ie average. This was observed, for example, at Shetland in 1960 following the appearance, in the catches, large numbers of parasite-free codling of 31 to 40 cm. The effect of this is shown by the lowering of ie percentage of infested fish in the stock of marketable-sized cod in the Shetland area in 1960. On the ther hand, it also seems possible that poor recruitment to the stocks, resulting in course of time in elatively small numbers of fish of 31-40 cm entering the fishery, might also affect the infestation values. ome evidence of this was found in 1961 off Aberdeenshire, where the overall infestation of marketable-zed fish rose more rapidly from its 1960 level than in the adjacent localities.

In order to eliminate the possible effect of brood fluctuations on the frequency of infestation per-ntages, the smaller marketable-sized fish of 31 to 50 cm have been omitted and Table VII has been repared to include only cod of over 50 cm. As may be expected, the omission of the 31 to 50 cm size-roup results in a general increase in the infestation values for the remaining larger cod in all areas. his increase is most noticeable in the North Sea. On the west of Scotland the difference is very small, ut this is not surprising considering the high proportion of adult cod in the stocks and the relatively gh infestation of the smaller marketable-sized fish in this region, each of which would tend to neutralise ny effect of brood fluctuations on the infestation values.

TABLE VII

PROPORTIONS OF WORM-INFESTED FISH AMONG COD OF 51 CM AND OVER

July 1958-September 1961

No. = number of cod examined; % = percentage infested

Area	1958		1959		1960		1961	
	No.	%	No.	%	No.	%	No.	%
. Abbs Head—Farne Is.	—	—	138	39·1	5	80·0	122	74·6
rth of Forth	33	9·1	44	22·7	134	37·3	42	71·4
uter Firth of Forth	27	11·1	45	28·9	51	41·2	77	46·8
erdeenshire coast	19	0·0	26	7·7	68	11·8	170	46·5
oray Firth	11	36·4	54	20·4	65	12·3	129	27·9
kney—Shetland—north coast	100	14·0	136	37·5	79	34·2	154	57·8
rthern North Sea (offshore)	87	1·1	10	0·0	96	12·5	102	9·8
est of Scotland	—	—	287	44·9	235	48·9	207	47·8

Although brood fluctuations in cod undoubtedly cause variations in the infestation frequencies, comparison of Tables VI and VII shows that the omission of the smaller fish has little effect on th relative proportions of the infested fish. Consequently, any effect produced by differences in the broo strengths would seem to be temporary. It would also appear that variations in the proportions of infeste fish are not entirely due to brood fluctuations and that in some cases another factor must be operating

A study of the size composition of the cod catches on the various grounds suggests that this facto might be the migration of adult fish from neighbouring areas where infestation is either heavier or lighter Some evidence in support of this view has been obtained from individual samples, but more particularl from the Moray Firth and Aberdeenshire coast areas where adult fish with a relatively high frequenc of infestation were more numerous in 1961 than in any previous year. This view is backed by the fac that the fisheries in these areas depend to some extent on a variable seasonal movement of adult cod o to the fishing grounds. Unfortunately the movements of adult cod in Scottish waters are not yet know in sufficient detail to permit a more accurate assessment of this aspect of the problem.

It may be concluded that, despite fluctuations in the proportions of infested fish in certain areas, a appreciable increase has occurred in the worm infestation of cod in all Scottish waters, with the possibl exception of the west of Scotland, since 1958. This increase is most noticeable on inshore grounds of th Scottish east coast from Aberdeenshire southwards to the Farne Islands. Furthermore, in spite of th fluctuations in some areas, it is remarkable that most of the eight localities or regions in Tables VI an VII show an increase (sometimes a very marked increase) from 1960 to 1961.

DISCUSSION

Commercial Implications

The evidence presented in the foregoing sections of this paper reveals a situation which must giv rise to some anxiety in regard to the state of cod stocks in Scottish coastal waters. Although this infesta tion has been known on western Scottish grounds for some time, the high proportion of the fish affecte and the intensity and extent of the infestation were not realised fully until revealed by the present in vestigations. Even more remarkable, however, is the discovery that the infestation affects such a hig proportion of cod on Scottish east coast grounds, hitherto believed to be relatively unaffected, an that the numbers of infested fish are growing in most areas. Some satisfaction may be derived from th fact that the main body of cod in the North Sea (i.e. beyond 30 miles from the coast) is as yet but littl affected, but even here there is evidence of a slight increase, and there are some reasons for believin that the heavier the infestation in coastal waters the heavier will it become on offshore areas. This ma arise in two ways, firstly, by cod native to the coastal zone becoming infested and moving offshore afte spawning and, secondly, by offshore cod coming into coastal waters to spawn and acquiring the parasit during their sojourn in these waters, before returning to their offshore haunts. These would appear t explain the occurrence of the small, but possibly increasing number of infested adult fish in the centra northern North Sea where the infestation of younger cod is negligible.

At the same time it must be borne in mind that Scottish east coast waters contain a dense populatio of young cod which is of considerable importance to Scottish inshore fisheries. To emphasise this point i should be explained that more than 500,000 cwt of cod are caught annually by Scottish fishermen in th North Sea and on western Scottish grounds and that from 80 to 90% of this total are taken in wate where infestation has been shown to be appreciable. Moreover, freshly caught cod and codling from the North Sea grounds is considered to be the highest quality product of its kind. It therefore is importa to consider how the change has been brought about and whether any remedial action can be taken.

Comparison with Canadian Results

One of the interesting features of the Scottish investigations is the close resemblance of the result to those of Canadian scientists working on the same problem. The growth of the infestation with th size and age of the fish, the variable frequency or degree of infestation from place to place, the muc higher infestation in coastal waters than offshore and the fact that the infestation is predominantly b

Porrocaecum decipiens, and insignificantly by *Anisakis*, are results common to the research in both countries. Only in a few respects do the results not entirely agree; for example, Scott and Martin (1959) concluded that cod may be infested by the time they are one year old and have reached a length of 13 cm. The smallest cod found with worms in Scottish waters measured 22 cm and was probably between $1\frac{1}{2}$ and $2\frac{1}{2}$ years old. Moreover, few cod below 30 cm in length were found to be affected in Scotland, but as already observed, it is possible that more fish of this size were affected, although not visibly in a macroscopic examination.

Scott and Martin (1957) also refer to a seasonal variation in the frequency and degree of infestation which they attribute to offshore and inshore migrational movements of cod. Although reference has already been made to variations in the frequency of the infestation in some Scottish areas, so far it has not been possible to demonstrate conclusively any seasonal variation in this feature. Despite the relative scarcity of adult fish such as would be taking part in migratory movements, some evidence of a variable frequency of infestation of big cod has at times been observed on the Scottish coast during the spawning period. Rather more suggestive evidence of the effect of fish movements has, however, been obtained from the degree of infestation as determined by the number of worms per 100 lb of fillets (Table IV).

Scott (1955) has shown experimentally that *Porrocaecum* eggs hatch into a larval stage which can survive in sea water for anything up to 13 days. In this free-living state the larvae are, however, unable to free themselves from their protective cuticle, and from this it is inferred that entry into some intermediate host is probably necessary before the cuticle can be dissolved. Failure to encounter a suitable host presumably results in the death of the larvae.

Because of the smallness of both the eggs and the free-living larvae it seems unlikely that they are ingested by cod; consequently an earlier and smaller intermediate host than the cod would seem to be essential in the life cycle of the parasite. Although the Canadians have some evidence that a mysid crustacean may act in this capacity this has not been conclusively demonstrated so far, and Myers (1960) has suggested that a first intermediate host may not be involved and that transmission may be by a carrier host.

Attempts to discover a first intermediate host in Scottish waters by examination of some of the food of cod at the size at which they become infested have hitherto proved unsuccessful. It is known that young cod feed chiefly on crustaceans, fish of less than 20 cm almost exclusively on small forms such as amphipods, mysids, euphausids, etc., and that the cod, as they grow, gradually turn to eating bigger types including natant decapods, such as *Crangon* and *Pandalus*, and fish. By the time cod have become obviously infested with *Porrocaecum* in Scottish waters they have almost ceased to eat mysids. It may well be, therefore, that the first intermediate host of the parasite, if such a host exists, must be an animal larger than a mysid, or else a transporter or carrier host must be assumed to convey the early stage of the parasite to the cod. This could be a crustacean or perhaps more likely a fish which preys on mysids or other small crustaceans and is itself eaten by cod.

Canadian and Scottish investigations also reach the same conclusion that the infestation of cod by *Porrocaecum decipiens* is effected by seals, which act as the definitive host for the parasite (Scott, 1953; Scott and Fisher, 1958; Rae, 1960). Canadian research has also demonstrated the relationship between worm infestation of cod and the number of seals present in the same area. Scott and Fisher (1958) have shown that in eastern Canada three seals, the common or harbour seal *Phoca vitulina* L., the Atlantic or grey seal, *Halichoerus grypus* (Fabricius), and the harp seal *Phoca groenlandica* Fabricius, are involved. Only two of these, the common and the grey, occur in Scottish waters but analysis of stomach contents has shown that both species contain *Porrocaecum decipiens*. Other nematodes found in the grey seal stomachs include species of *Anisakis* and *Contracaecum*. It would appear, therefore, that in addition to serving as the definitive host of *Porracaecum decipiens*, the dominant parasite of cod flesh, in Scottish waters seals also may act as the definitive host to the species of *Anisakis* which also occurs in cod and in other fishes (see also Margolis, 1954).

Relationship of the Incidence of Worm-infested Cod and the Distribution of Seals

Reference has been made elsewhere (Rae, 1960) to the greater numbers of nematodes found in the grey seal than in the common. Further counts of the numbers of worms found in seal stomachs have

been made in 1960 and 1961. In 14 common seals of different ages the numbers ranged from 3 to 50 with an average of 17; while in 17 grey seals they ranged from 3 to 750 with an average of 176. These records confirm that the grey seal is a heavier vector of the nematode, *Porrocaecum*, than the common seal. It is, therefore, of interest to consider the distribution of grey and common seals in relationship to the incidence of *Porrocaecum decipiens* in cod in Scottish waters.

The last column of Table I gives the numbers of cod of marketable size, together with the numbers and percentage of those with worms in their flesh. On the assumption that the proportions of cod sampled in the various size-groups are more or less representative of the stocks in these areas, the percentage of marketable fish with worms may be regarded as a general measure of infestation in each locality or region in Scottish waters. This again demonstrates the high worm-infestation on western grounds, from north-west Scotland southwards to the Irish coast and Firth of Clyde, and emphasises particularly the serious nature of the problem in south-west Scotland where half the fish are affected. Within the North Sea surprisingly high numbers are shown to be affected in coastal grounds of East Shetland and from the Firth of Forth southwards to the Farne Deeps.

The percentages of marketable-sized cod with nematodes in their flesh in each statistical rectangle and in the various combinations of rectangles as listed in Table I are shown in Figure 2. The same figure also gives the rough distributions of the grey and common seals on the Scottish and east English coasts as regards (a) the colonies where concentrations of seals occur at the breeding season and (b) the normal occurrence of seals, whether adult or adolescent, in their variable concentrations throughout the year.

On the whole, the common seal is recognised as a non-migratory species with its main centres of distribution in sheltered waters. Although the grey seal is known at certain times of its life to undertake long-distance movements, including the crossing of the Faroe-Shetland Channel and of the North Sea, there is no evidence to show that it lives for any appreciable time in deep-water offshore regions. Indeed, from direct observation on research vessels over the past thirty years and from the replies by fishermen to enquiries on this subject it would appear that the grey seal, like the common seal, is very largely coastal in distribution, and tagging experiments on juveniles suggest that their movements are largely coast-wise, except for the apparently speedy sea-crossings to other coastal regions.

The relationship between the coastal distribution of seals and the coastal incidence of *Porrocaecum decipiens* in cod is noteworthy. If the high incidence of cod-worm on offshore western grounds seems inconsistent with this view, the explanation is fairly obvious. In the first place, grey seals are known to breed at North Rona, on islands at the western entrance to the Sound of Harris, on St. Kilda, at various places from Barra Head to the Treshnish Isles, on Oronsay and in Northern Ireland, and to be present in non-breeding concentrations at Sulisker, Flannan Isles, Skerryvore and Dubh Artach. Few, if any, of the western grounds sampled for cod (Figure 1) can therefore be more than thirty miles from the nearest concentration of this animal. Further, it has been already noted that young immature cod are rarely taken west of 7°W longitude, thus indicating the absence of cod nursery grounds in this region. The high infestation of adult cod on these grounds, therefore, may also result to some extent from the movement offshore of cod from coastal nursery grounds such as the Minch and the Clyde, where infestation is known to be high in the young fish.

The low infestation of cod in the North Sea outside thirty miles from the Scottish coast seems to fit with the scarcity of reports of seals seen offshore in this region. Furthermore, the absence of reports of any marked infestation of cod in coastal waters of the countries bordering on the southern and eastern North Sea may be explained in some measure by the rigorous control of the relatively small seal stocks known to exist in these countries (Rae, 1960).

Growth of the Worm Infestation of Cod in Scottish Waters

At the passing of the first Grey Seals Protection Act 1914 the grey seal population of Scotland was said to be as low as 500 animals, although this may have been much too low an estimate. At the same time the common seal was numerous on the west coast, at Shetland and Orkney, and in sheltered waters of the east coast such as the Firth of Tay. Some years later Williamson (1919) recorded the first observations of *Porrocaecum* (*Ascaris*) *decipiens* in cod from Rona (north-west Scotland). Williamson also referred to the absence of this parasite from North Sea and Shetland cod. By the late 1920s, when Ritchie and

Calderwood (1928) estimated the grey seal population at between 4,000 and 5,000 (again possibly an under-estimate), most of which were located in the west of Scotland, worm infestation had been recorded at various points on the west coast. From accounts of visits to North Rona by Harrisson (1932) and Darling (1939) it would appear that a marked increase in the numbers of grey seals took place on the west coast in the 1930s. About the same time Gunn (1932) recorded the first indications of an increase in the numbers of this animal at the Orkneys. These events were followed by reports indicating the spread of *Porrocaecum decipiens* on western grounds and its appearance in North Sea cod (p. 18).

After the Second Great War, salmon fishermen reported rapidly increasing numbers of seals on all Scottish coasts, but especially on the east coast. In particular Hickling (1957) and Rae (1960) provide evidence pointing to the growth of the grey seal populations of the Farnes and the Orkneys respectively. If it has to be admitted that the early evidence regarding the numbers of seals in various colonies leaves something to be desired, this is of the nature of investigations such as these; methods have improved with increasing knowledge. While few experienced naturalists will believe that the Scottish population of grey seals in 1914 was anything like as low as 500, probably none has any doubt that the 1914 population was very much lower than the present-day estimate of around 30,000 (see Report of Consultative Committee on Grey Seals and Fisheries 1963). Unfortunately, even the evidence for the widely accepted increase in the Farnes population cannot be precise, but again few if any will doubt that there has been a very considerable increase there during the last fifty years; all the available evidence points in the same direction in the case of the Orkney population and possibly others have increased in a similar way.

These evident increases in the numbers of seals have been accompanied by the increase in the infestation of cod by *Porrocaecum* in the coastal waters of eastern Scotland, described in this paper, which, though necessarily measured with a similar lack of precision, appears nevertheless to be equally certain.

It has also been shown that this infestation is still growing, both in the numbers of fish affected and in the average number of worms in the individual affected fish. This growth is apparent in different localities but is most noticeable on grounds off the east coast of the Scottish mainland. This could be related to the demonstrable expansion of the grey seal stocks in this area. Serious though the infestation already is in Scottish coastal regions, there is some reason to fear that it will attain even greater proportions. This tentative conclusion is based on the indications that the growth of the infestation may have, reasonably, lagged somewhat behind the growth of the seal stocks.

Influence of Ecological Conditions on Infestation

Despite the relationship between the number of seals and the number of worm-infested cod some features of this problem suggest that other factors may play a part in determining the frequency and degree of infestation. For example it has been observed that in the Firth of Clyde and certain other sheltered localities on the west of Scotland, where the seal population consists mainly of common seals, in which the load of *Porrocaecum* is lighter than in the grey seal, the infestation of cod is nevertheless high. Scott and Martin (1959) have stated that in the Lockeport area of Nova Scotia a few harbour (common) seals are capable of maintaining a high level of nematode infection in inshore cod. It would appear, therefore, that under certain conditions the infestation of cod by nematode larvae may be heavier than would seem possible from the numbers of seals on the grounds. Such localities on the west of Scotland are characterised by comparatively weak tidal streams or currents and by the deposition of mud or fine silt on the sea bottom thus favouring the growth of a distinctive fauna.

On the other hand at North Rona (which, in the last four months of every year at least, has a larger concentration of grey seals than any other British locality), in the Orkneys and in some parts of Shetland, where both species of seal occur in considerable numbers, the infestation of cod is perhaps not so heavy as might have been expected. In these areas stronger tides and currents, in addition to greater exposure to open-sea weather conditions generally, ensure a considerable water disturbance and scouring force with the result that bottom deposits and their resident faunas are very different from those of the inshore, sheltered areas.

It seems possible, therefore, that ecological conditions play some part in determining the extent of the cod-worm infestation in the different areas. In the first place these conditions may be either favourable

or unfavourable to the existence of the first intermediate host, or carrier host, available for the free-living stage of the *Porrocaecum* larvae, and secondly, dependent on the animal community throughout the year, they may or may not attract shoals of cod, the second intermediate host, in their search for food.

Although there is no evidence to suggest that the eggs and free-living larvae of *Porrocaecum* are anything but demersal in habit it seems reasonable to assume that on hard grounds, subject to the influence of strong tides and currents, a considerable dispersal of eggs and larvae takes place, thus reducing their density and the chances of infestation of the intermediate or carrier hosts in the immediate vicinity. On the other hand, in those slack-tidal areas where eggs and free-living larvae tend to remain in some concentration the possibilities of the infection of the intermediate hosts would seem to be greater. It appears possible, therefore, that purely physical conditions in the sea may also have some effect on the extent and degree of worm infestation of cod in some localities.

Remedial Measures

The growth of any undesirable parasitic infestation of commercially important fish stocks naturally raises the question of how to deal with the problem.

It has been suggested that fishermen should avoid fishing in areas in which worm-infested cod are common, but this is clearly impracticable as the affected areas provide the bulk of the cod caught by Scottish vessels in the North Sea and on western grounds. Moreover this suggestion ignores the effect of the movements of cod shoals from one area to another. It has also been suggested that since worm infestation is heaviest in big cod an effort should be made to improve the quantity of worm-free cod by reducing stocks of the bigger fish. In view of the present intensity of fishing, however, it is doubtful if the stocks of big cod could properly be reduced further in home waters and in any case it has been shown that the infestation is increasing in all sizes of cod from the minimum marketable size upwards.

Worm infestation may occasionally be tackled by an examination of the catches on the market. This method, however, cannot be applied to the cod, in which the parasites are not discovered until after the fish are cut up by the merchants. Fish merchants may provide for the detection and removal of worms by filleting the fish and by candling the fillets (Power, 1957; 1961) but this method is not fully effective. Moreover this treatment adds considerably to the costs of processing the fish.

There remains the possibility of action against the parasite in its natural life cycle. In addition to the seal and the cod the life cycle of *Porrocaecum* may involve another animal or animals, as yet unknown, but, even if the life cycle were fully understood no effective measures to reduce the worm infestation of cod seem possible against the parasite in its early stages. Undoubtedly the most promising approach to the problem would seem to be through an effort to control the adult stage of the worm by a reduction of the numbers in its final host, the seal.

SUMMARY

From July 1958 to September 1961 more than 8200 cod from Scottish waters were examined for the presence of larval nematode worms (*Porrocaecum decipiens*) in their flesh.

Few codling of below marketable size, 30 cm, are affected. In fish of 31-50 cm the infestation is appreciable and with the growth of the fish it increases to a maximum frequency in adult cod of over 70 cm. Infestation is heaviest on the west of Scotland, particularly on inshore grounds such as the Firth of Clyde and parts of the Minch. In the North Sea infestation is mainly confined to coastal waters extending from the north of Shetland to the Farne Islands and to a distance of 30 miles from land. In some localities, notably from the Firth of Forth southwards to the Farne Islands, the proportion of cod affected is nearly as great as on the west of Scotland.

The degree of infestation, as measured by the number of worms per infested fish, also appears to increase with the growth of the fish, although the number of worms per 100 lb of fillets declines somewhat in fish of 71 cm and over. Possible reasons for this anomaly, which has previously been observed by the Canadians, are discussed.

A survey of relevant scientific literature on the subject, considered in conjunction with the results of ne investigations for 1958 to 1961, indicates an increase in the worm infestation of cod in the Scottish rea. This is particularly evident in coastal waters on the east of Scotland.

The results of the investigation are compared with those of Canadian scientists working on a similar roblem. In each country seals are regarded as the definitive host of the parasite.

The growth of this infestation is associated with the distribution and increase in the numbers of als, particularly grey seals, round the Scottish coast in the past 30 years. The possible influence of her factors is discussed.

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